Dynamical Climatology

The impact of aircraft observations on analyses and forecasts from the operational 15—level model.

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DYNAMICAL CLIMATOLOGY TECHNICAL NOTE NO. 20

THE IMPACT OF AIRCRAFT OBSERVATIONS ON ANALYSES AND FORECASTS FROM THE OPERATIONAL 15-LEVEL MODEL

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1. Introduction

The extent to which observations from aircraft affect analyses and forecasts from a numerical weather prediction model may be measured in an Observing Systems Experiment (OSE) in which parallel runs with and without aircraft data are performed and the results compared. The change in model fields produced by inclusion of aircraft observations represents their 'impact'. This is assessed by the magnitude of the change in analyses and the effect on the skill of forecasts produced from them. Further study of differences in localised areas indicates some of the reasons for these changes.

An OSE to assess the impact of aircraft observations has been carried out using data for periods in February 1979 (Barwell 1982) and November 1979 (Lorenc 1982). Preliminary results from the latter period were presented at a study conference (Gilchrist 1982) and a fuller report has been published recently (Barwell and Lorenc 1985, hereafter referred to as BL). Similar experiments for the same period have also been performed jointly by the European Centre for Medium Range Weather Forecasts (ECMWF) and the Royal Netherlands Meteorological Institute (Baede et al 1983).

With the introduction of a global operational forecast model in the Meteorological Office, OSEs can now be performed in the current operational environment using global observational data. The aircraft OSE for the November period has been repeated with the new model to test the experimental procedure for conducting such experiments and to compare the results with previous work. This note reports the results of this comparison. Section 2 describes the salient features of the models and analysis schemes used for the current and previous OSEs; section 3 assesses the effect of aircraft observations on analyses and forecasts and section 4 compares the results with previous OSEs with particular emphasis on differences in the analysis schemes used. Finally, a summary and conclusions are presented in section 5.

2. Experimental details

a. Previous studies

The experiments described in BL used substantially the same model and analysis scheme as that used to generate analyses in near real time during the special observing periods of the First GARP Global Experiment (FGGE) (Lyne et al 1982). A global 11-layer general circulation model with a 220 km resolution (Saker 1975) was used, hereafter referred to as the UK11 model. The analysis scheme used optimum interpolation with repeated insertion of data as described by Birch and Lyne (1975) but with some tuning (Barwell 1982). In particular, the scaling factor for analysis increments was changed to increase from zero to 0.5 over the six-hour repeated insertion period. Single-level observations such as AIREPs were used to update the nearest model level only, and no divergence damping or other technique to control gravity waves was applied.

The ECMWF work used a 15-level model with a 1.875° resolution hereafter referred to as the EC15 model. Data assimilation consisted of a multivariate scheme to maintain a balance between mass and wind fields followed by a non-linear normal mode initialization step. Observations were allowed to influence several model levels rather than just the nearest. Details of the assimilation scheme are given in Bengtsson et al (1982).

b. Current system

The experiments described in this note were performed with a version of the numerical forecasting system used operationally in the Meteorological Office. This uses a global model on 15 irregularly spaced sigma levels extending into the lower stratosphere. It has a resolution of 1.5° in latitude and 1.875° in longitude and uses a 15-minute time step. A description of the model is given by Foreman (1983) and in more detail by Dickinson and Temperton (1984). The version used for the present work will be referred to as the UK15 model and incorporates all changes made operationally up to 15 July 1983.

c. Observations

The observation data set used here (and also in the OSEs referred to in (a) above) was that collected in delayed mode during FGGE (level IIb data). The compilation of this data set for use in observing system design and in data assimilation studies was one of the objectives of FGGE (GARP 1973). In addition to conventional aircraft (AIREP) reports, it contains aircraft observations transmitted by satellite (ASDAR) or recorded in flight for later processing (AIDS). The increased volume and better quality of data from these automatic systems make the FGGE level IIb data set particularly suitable for OSEs.

d. Analysis scheme

The analysis scheme used with the UK15 model has been outlined by Bell (1983). Assimilation is performed in six-hour cycles using an optimum interpolation scheme similar to that used by the UK11 model. The observations are first subjected to a quality control step. Optimum interpolation is then used to compute weights for the assimilation, which is performed by insertion of the increments at each time step during the six hours up to the nominal data time. Analysis increments are scaled by a factor which varies linearly with time from zero to 0.125 over this six-hour period. In addition, geostrophic wind increments are applied to improve the assimilation of data into the mass field and hydrostatic temperature increments are used to improve the fit to surface pressure data. Divergence damping is also applied to control the level of gravity wave noise. Details of the assimilation scheme including the prescribed observational errors can be found in Lyne et al (1983).

e. Details of runs

The period studied was identical to that used in BL and is shown in Fig. 1. Starting from the ECMWF FGGE analysis for 00Z 9 November 1979, two parallel data assimilation runs were performed for the 48 hours to 00Z 11 November, one with and one without aircraft data (runs (a) and (b) in the

figure). Three-day forecasts were carried out to 00Z 14 November for each run (runs (d) and (e)) and the assimilation with aircraft data was continued throughout the same period to provide control analyses (run (c)). The effect of aircraft data on analyses and forecasts is assessed by their difference from the control analyses. More detailed study of particular areas highlights these differences and, by comparison with the original OSE using the UK11 model, identifies features due to the different analysis schemes used.

3. Assessment of impact

a. General

The greatest analysis differences between runs with and without aircraft data occur in the upper troposphere of the northern hemisphere where the density of observations is greatest. Figure 2 shows 250 mb wind differences for the northern hemisphere at the end of the two-day assimilation period. Arrows and isotachs show the differences in the sense with-aircraft analysis minus without-aircraft analysis for the present work (Fig. 2a), and, for comparison, the corresponding chart for the original study with the UK11 model (Fig. 2b). The wind difference depends to some extent on the magnitude of errors in the background field and hence on the characteristics of the model used, so that similar patterns would not necessarily be expected in the two figures. Consequently, large wind differences should not be regarded as a measure of the quality of the analysis since they could be due to an analysis scheme which fitted the observations more closely - which is desirable, or a background field with larger errors - which is undesirable. However, subject to these qualifications, some useful information about the general distribution of impact can be obtained.

First, the largest wind differences occur over the oceans where aircraft observations form a significant part of the observing network. In the southern hemisphere (not shown) aircraft data are sparse and wind differences are small, exceeding 5 m/s in only a few regions.

Secondly, the wind differences from the UK15 model (Fig. 2a) constitute a smoother field than those from the UK11 model (Fig. 2b). For the latter model large but localised wind differences occur in several places especially over the north-west Pacific and off the north-west African coast. The corresponding differences for 12-hour forecasts (Fig. 3b) show similar features not always easily correlated with analysis differences, and the north-west Pacific area in particular shows a very disorganised pattern. Some details of the differences in this area were examined by Lorenc (1982) who showed that the analysis differences were largely ageostrophic and contained a significant divergent wind component. The analyses from the UK15 model are smoother and show a more noticeable rotational component (see for example the two areas of difference over the North Atlantic at about 25-30N in Fig. 2a). The 12-hour forecast differences for this model also have the same smoother and more organised appearance (Fig. 3a).

We now proceed to study more detailed results from the experiment with the UK15 model concentrating on the North Atlantic and North Pacific oceans.

b. North Atlantic analyses

Fig. 4 shows the North Atlantic 250 mb analyses for 00Z 11/11/79 from runs with aircraft data (a) and without aircraft (b). The observations used in each analysis are also shown on the charts though some are omitted where they would obscure others plotted. Fig. 5 shows the difference between Figs. 4a and 4b.

The main features of the North Atlantic analysis are the broad westerly jet with the strongest winds close to the North American coast, and the extensive trough in mid-ocean to the south. The difference chart shows no significant features over North America or Western Europe where plenty of data from sources other than aircraft are available but differences occur in the details of the analysis of the trough, especially in the wind field.

On the upstream side of the trough, the with-aircraft analysis has a sharper ridge at the jet exit around 45°N 45°W and an increase in the flow into the trough itself. Also the position of the trough axis at this latitude, as indicated in the wind field, is further east. These changes are consistent with the assimilation of the two AIREPs at about 47°N between 30°W and 45°W indicating near-northerly winds of 55-65 kt. In the without-aircraft analysis the only wind observation in the area is a satellite wind of 35 kt in a more westerly direction. Similar observation and analysis differences occur at 300 mb. The overall effect is to divert more flow from the jet into the trough, increase the wind speeds round the ridge and sharpen the ridge itself. These features can be clearly seen on the difference chart (Fig. 5).

The trough is deeper and sharper in the with-aircraft analysis and has an increased wind shear across its axis. A line of aircraft observations on the south-eastern side of the trough and parallel to its axis has shifted the analysed wind maximum nearer to the axis and increased the speed by 10-20 m/s. Similar observations occur at 300 mb with the same effect. In Fig. 5 this difference appears as a 'dipole' pattern, heights being reduced on the trough axis and increased to the south east with increased wind along the dipole axis. This pattern indicates that some geostrophic adjustment has taken place during the assimilation procedure thereby reducing the level of ageostrophy introduced into the analysis. Such geostrophic balance was noticeably absent from experiments with the UK11 model (Lorenc (1982) - see, for example, Figs. 5, 22 and 27). This point will be discussed further in section 4.

c. North Atlantic forecasts

Figures 6 and 7 show forecasts from the with-aircraft and without-aircraft analyses for 00Z 11 November 1979 (Figs. 4a and 4b respectively), and Fig. 8 shows the difference between these forecasts. Charts are shown for forecast periods of 6, 12, 24, 36, 48 and 72 hours, and verifying analyses from the same times are presented in Fig. 9.

The evolution of the major features in Figs. 6 and 7 is very similar but local differences exist and can be traced through the forecast period. In particular, the increased wind speed on the downstream side of the trough in the with-aircraft analysis persists throughout the 72 hours as shown in Fig. 8. The associated dipole pattern in the height differences is also preserved, though with some distortion due to local wind shear. This pattern acts to preserve a slightly deeper trough in the forecasts and an intensified ridge ahead of it.

The wind differences around 45°N 40°W in the analyses are largely dissipated in the first twelve hours of the forecast. The reason is not entirely clear but the area is one of large flow curvature and the observations causing the differences affect the direction as well as the strength of the wind. In such circumstances, non-linear interactions may occur more readily to prevent geostrophic adjustment and dissipate wind differences via gravity waves.

Comparing the forecasts with the verifying analyses of Fig. 9, some differences are apparent. Up to T+12 the main trough is fairly well forecast, but the production of a cut-off low in the base of the trough which actually occurs before T+18 barely occurs before T+24 in the forecasts. From about T+36 onwards the development of the trough is badly forecast; the original cut-off develops its own circulation and becomes an independent feature while the residual trough intensifies and eventually cuts off in turn. These features are not generated by either forecast; instead the trough is simply elongated and slowly filled. Clearly, by T+24, the improvements that aircraft data have made to the intensity of the trough and the wind speeds around it are beginning to be overtaken by model errors and the effect of analysis errors unrelated to aircraft data.

d. North Pacific analyses

The 250 mb with-aircraft and without-aircraft analyses over the North Pacific at 00Z 11 November 1979 are shown in Fig. 10 and the difference between them in Fig. 11. These figures correspond to Figs. 4 and 5 for the North Atlantic and are shown with the same contour intervals for height and isotach fields.

The major areas of difference occur near the axis of the trough at about 30°N 170°E. As in the North Atlantic case, there is an increase in wind on both sides of the axis in the analysis with aircraft data leading to a sharper trough in the analysed wind field. The increase downstream of the axis is largely due to the AIREP at 34°N 175°E and amounts to about 20 m/s locally with some upstream extension of the jet and increase of wind shear across the trough axis. As in Fig. 5, Fig. 11 shows a limited amount of geostrophic balance in this area and the same 'dipole' pattern in the height differences. These characteristics were not present in the original OSE (Lorenc 1982).

On the upstream side, the region of strong winds extends deeper into the trough in the analysis with aircraft data although there are few observation differences at the analysis time. Similar regions of strong winds downstream of a jet exit were noticed in Barwell (1982) and attributed to increases of wind in the jet where aircraft are plentiful advecting into regions where few data are available to resolve analysis differences. It is likely that the effect observed here has a similar explanation.

The analysis differences mentioned above are very similar to those found by Lorenc (1982) using the UK11 model and also by ECMWF using the EC15 model (Baede et al 1983) indicating that the observed impact was a response to aircraft data and not a function of the model used. Thus, in at least one area a substantial impact can be attributed to individual aircraft reports.

e. North Pacific forecasts

Figs. 12-15 show the forecasts from the with-aircraft analysis, the forecast from the without-aircraft analysis, the difference between them and the verifying analyses respectively. The layout of these diagrams is the same as for Figs. 6-9. Both forecasts show similar features to the North Atlantic case in that they predict an elongation of the trough rather than the disruption which actually occurs. This disruption was also not forecast by the UK11 model (Lorenc 1982) but was generated by both with-aircraft and without-aircraft forecasts in ECMWF's work (Baede et al 1983) indicating that model errors or analysis errors other than those due to aircraft account for the incorrect treatment of this feature. Another similarity with the Atlantic case is that the area of increased wind speed on the downstream side of the trough persists throughout the forecast even after T+24 when model errors are beginning to become dominant.

The trough at 50°N cuts off earlier than predicted by either forecast and moves eastwards more quickly. Both its intensity and position are better forecast from the with-aircraft analysis although neither forecast is very good at T+72. (The large differences in Fig. 14 at T+72 near 150°W reflect the improvement in position). Similar improvements were also found in BL using the UK11 model and by ECMWF (Baede et al 1983 - whose Fig. 5 corresponds to charts for T+48) indicating that they have been generated by the aircraft data.

f. Data selection effects

Some local analysis differences were found at a few places in the southern hemisphere where there were no aircraft observations which could have been directly responsible. The effect was found to be caused by the initial quality control check in which an observation is flagged for rejection if sufficiently different from the background field. In one case illustrated in Fig. 16 a depression deeper than analysed by the model passed close to two drifting buoys at about 54.4°S 3.3°E. The effect of aircraft data on the background field for the with-aircraft run was small in this area at 00Z on 10 November but just enough to tip the scales in

favour of retention rather than rejection of the surface pressure data from these buoys. If rejection occurs the observations no longer affect the analysis and further rejection is more likely at subsequent times as long as the reported pressure remains low. In this case the buoy reports for both 00Z and 06Z on 10 November were rejected in the run without aircraft data but not in that with aircraft data. By 00Z 11 November the two analyses are in agreement again at the buoy locations but differences of around 5 mb remain in a small area downstream. It would be a mistake to generalise by saying that such differences always indicate a beneficial effect of aircraft data, because it is conceivable that aircraft could tip the scales in favour of rejection of other data in some cases; (in fact such an instance was also noticed in the southern hemisphere) but this example does serve as a reminder that in an analysis scheme in which all observations are assimilated simultaneously, the removal of any one observing system also removes its interactions with other systems, with consequent changes in the effect of these other systems on the analysis produced.

4. Assimilation Schemes

a. General

At several points in this report mention has been made of the effect of different analysis schemes used. This section summarises these differences and illustrates some of the points in more detail by comparing the original experiment using the UK11 model with the re-run using the UK15 model.

It is instructive to examine the impact on the wind field by splitting it into three components. Any wind difference field such as that in Fig. 11 can be divided into a divergent component ($\underline{V}_d$) and a rotational component ($\underline{V}_r$). The latter can be further divided into a component in geostrophic balance with the height field ($\underline{V}_g$) and an ageostrophic rotational component ($\underline{V}_{ar}$), ie.,

$$\underline{V} = \underline{V}_r + \underline{V}_d = \underline{V}_g + \underline{V}_{ar} + \underline{V}_d$$

In Fig. 17 this analysis is applied to the region of the North Pacific round the AIREP at 34°N 175°W referred to in section 3(d). The charts show the components $\underline{V}_g$ (top), $\underline{V}_{ar}$ (middle) and $\underline{V}_d$ (bottom) for the 250 mb wind differences from Fig. 11 (left) and from the original OSE using the UK11 model (right).

Fig. 18 shows the mean square wind speed for each of the charts of Fig. 17 presented in bar chart form. The bars for the two experiments are scaled to the same height but the widths are proportional to the actual values so that equal areas represent equal mean square winds. Numbers represent the percentage of the height of each bar due to each component of the wind. The mean square values for each component in $(m/s)^2$ are as follows:

	UK15 model	UK11 model
Geostrophic component	35.4	25.1
Ageostrophic rotational cpt.	34.3	118.2
Divergent component	3.9	31.4

b. Geostrophic balance

Figs. 17 and 18 show that the UK15 model has adjusted to a state having approximately equal kinetic energy in geostrophic and ageostrophic components of the difference field. The dipole pattern in the height field (top left in Fig. 17) is characteristic of a wind increment such as that produced by an AIREP observation and has been pointed out in the cases studied in section 3. It is produced by geostrophic adjustment during the repeated insertion period. Experiments with idealised wind perturbations reported in BL show that wind increments are retained better during forecasts if balanced by such geostrophic height increments. Figs. 17 and 18 show that in the UK11 model little geostrophic adjustment has taken place during the assimilation and wind differences are dominated by the ageostrophic component. After a 6-hour forecast, some adjustment could be detected and a more typical dipole pattern appeared but by then much of the wind increment had disappeared.

c. Divergent wind

It is clear from Figs. 17 and 18 that in the UK15 model the analysis scheme has had a much smaller impact on the divergent component of the wind both in absolute terms and relative to the overall level of impact. This is a desirable quality of an analysis scheme since the divergent wind component gives rise to high frequency gravity waves which disperse and are damped out. Perturbation experiments in BL clearly illustrate these gravity waves and show that the effect of observational wind data is retained much better if the data is used to update the rotational component of the wind.

d. Vertical distribution

Fig. 19 shows the impact of aircraft data on the analyses for 00Z 11 November 1979 at 200 mb (top), 250 mb (middle) and 300 mb (bottom) for the UK15 model (left) and the UK11 model (right). The charts cover part of the south-east Indian Ocean (the coast of north-west Australia appears in the bottom right corner). This region was chosen because the only aircraft observation in the area was an AIREP at 18°S 111.1°E (centre of chart area) reporting a wind of 280° 60 kt at 238 mb. Fig. 20 shows the mean square wind speed for each of the charts of Fig. 19 in bar chart form. Clearly, in the UK11 model the influence of the AIREP has spread very little to other levels whereas in the UK15 model the observation is deliberately made to influence a range of model levels during assimilation. In BL it is demonstrated that spreading the effect of an observation over a greater vertical extent promotes more rapid geostrophic adjustment and less dissipation of wind increments. The generation by the UK15 model of a more geostrophically balanced analysis with a less divergent wind field as shown in Fig. 16 can now be related to the way the analysis scheme uses observations to influence several model levels rather than just the nearest.

Because the UK15 model achieves a more balanced state and retains increments better, a good analysis can be produced using smaller weights for analysis increments at each time step during the repeated insertion procedure. As mentioned in section 2, the UK11 model uses larger weights to force the analysis to fit the data, but since geostrophic adjustment is slower, much of the assimilated information is dissipated by gravity waves in the early stages of forecasts. The result is a 'noisy' analysis, especially in the absence of divergence damping. Furthermore, the gravity wave noise interacts with the repeated insertion procedure to degrade the analysis further. The vertical distribution of aircraft wind data in the UK15 model together with divergence damping therefore enables good model analyses to be produced without excessive 'observation forcing' or gravity wave noise.

5. Summary and Conclusions

An experiment to assess the impact of aircraft observations on numerical model analyses and forecasts has been performed with the Meteorological Office's operational 15-level model, allowing comparison with previous experiments (Barwell and Lorenc 1985, Baede et al 1983). The main influence of aircraft data occurred in the upper troposphere over the northern hemisphere oceans and was qualitatively similar to that found in the earlier work. Small but detectable improvements were found in analyses and forecasts of the positions and intensities of upper troughs and of the flow round them. Although much of the improvement was lost during the early stages of a forecast, some effects were retained for several days. However, after about 24 hours, the forecasts were degraded as model errors became dominant.

Some improvements in the details of the analyses were attributable to improvements in the assimilation and analysis schemes used by the 15-level model. The amount of small-scale vertical structure in the wind analyses was reduced by the use of an assimilation scheme in which each aircraft observation is used to influence several model levels rather than just the nearest. Geostrophic adjustment then takes place more rapidly during assimilation resulting in a greater degree of geostrophic balance in the

analyses. In addition, the amount of divergence in the wind increments was greatly reduced in analyses, indicating that aircraft wind observations were used mainly to modify the rotational component of the wind field. The use of divergence damping by the analysis scheme together with the faster geostrophic adjustment act to produce this effect, which reduces the loss of assimilated information through gravity waves in the early stages of forecasts.

Using a simple linearised model to study the assimiation of single-level wind data, Barwell and Lorenc (1985) showed that retention of information could be improved by more geostrophic balance and less divergence in analyses. Thus the characteristics of the assimilation and analysis schemes used by the 15-level model generate analyses which are more effective in retaining the information assimilated from aircraft observations and in generating improvements in forecasts.

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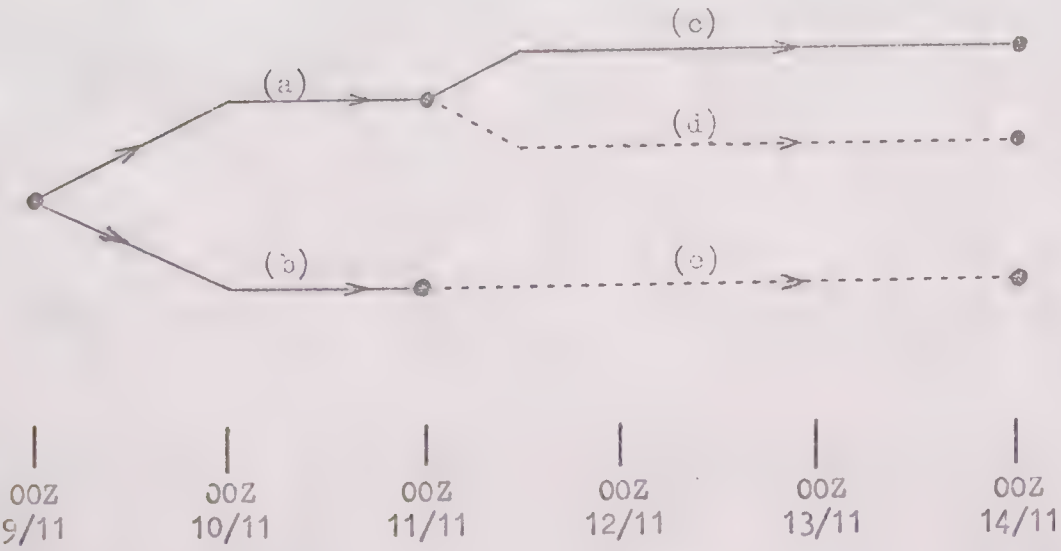
Figure 1. Details of model runs performed for experiments. Analyses are shown as full lines and forecasts as dotted lines. Dates are in November 1979.



(a) Assimilation with aircraft data.

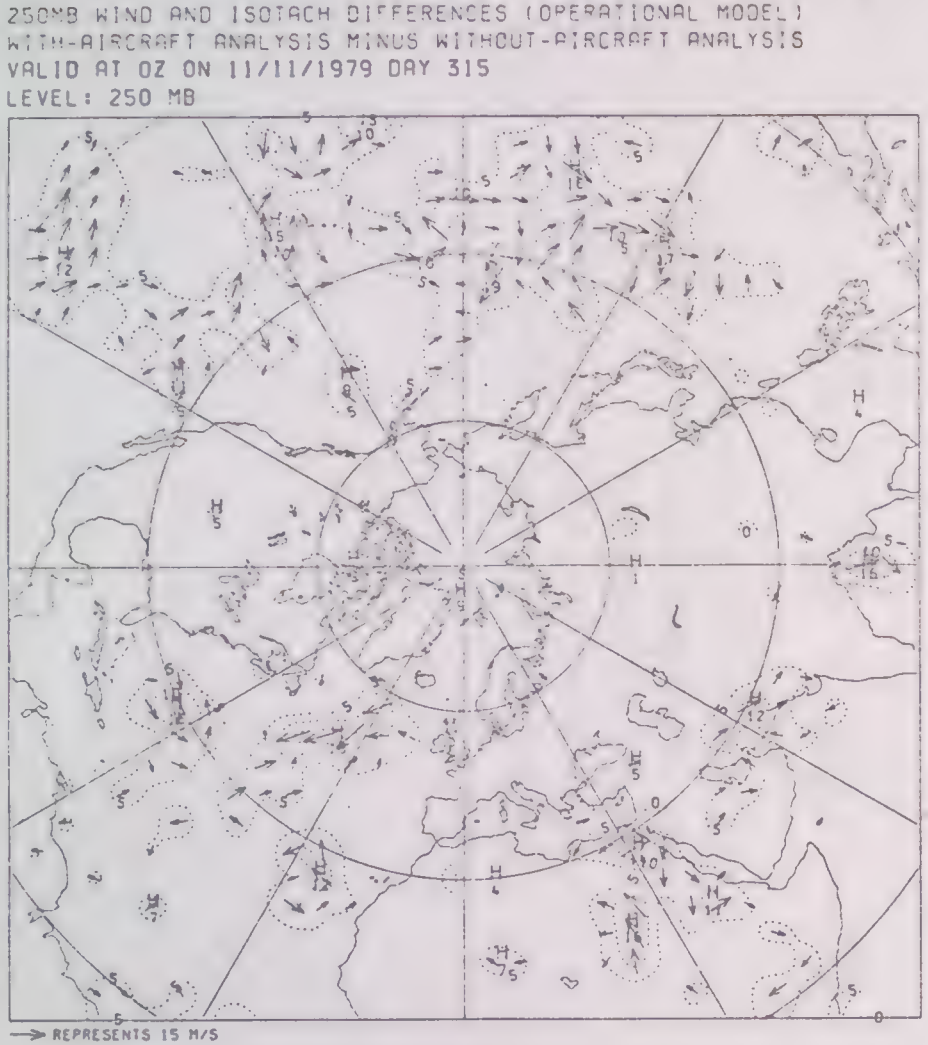
(b) Assimilation without aircraft data.

(c) Control assimilation.

(d) Forecast from analysis with aircraft data.

(e) Forecast from analysis without aircraft data.

Figure 2. 250 mb wind differences between analyses with and without aircraft data. Charts are for the UK15 model (left) and the UK11 model (right). Isotach interval is 5 m/s.



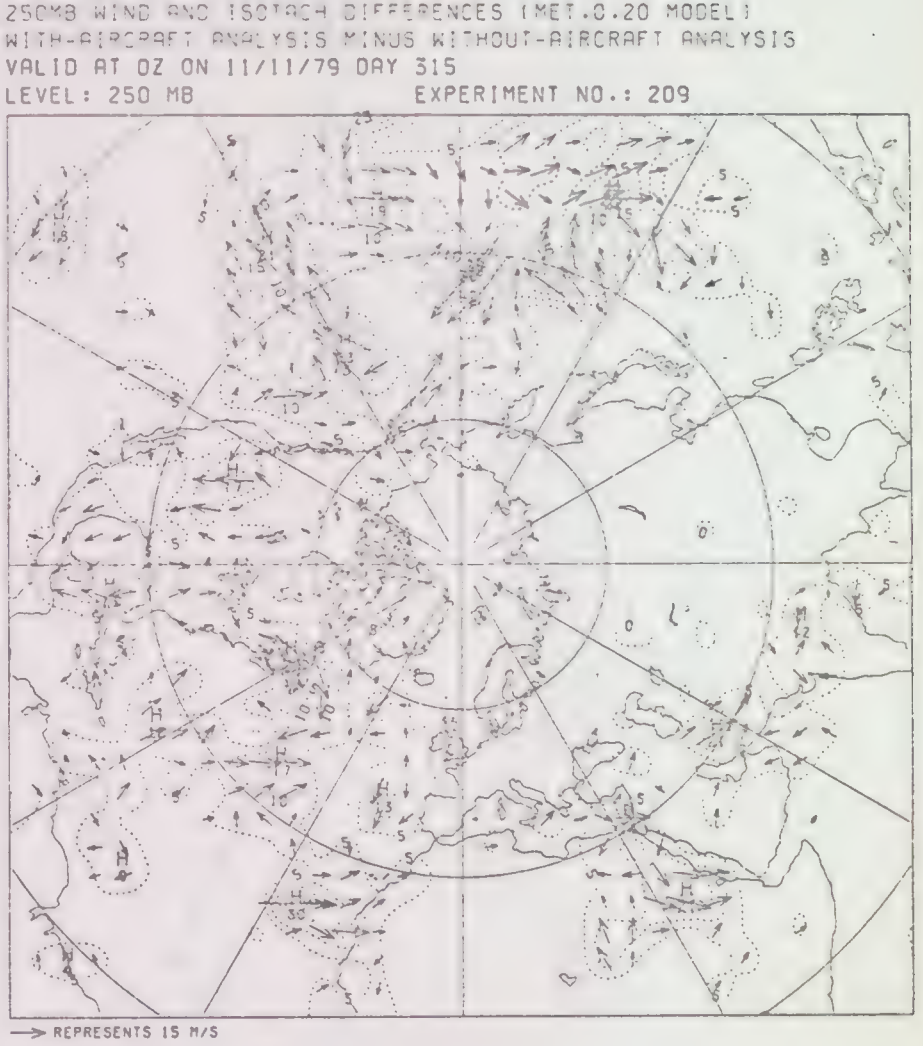
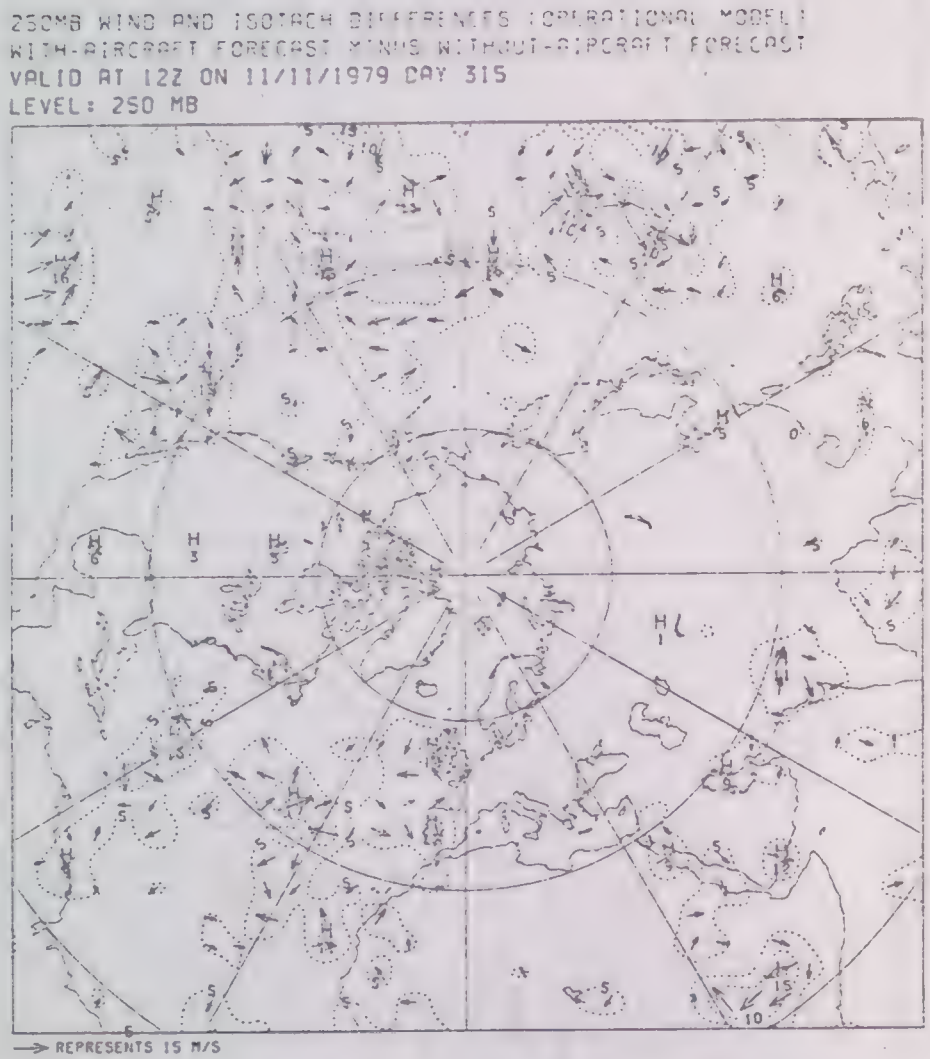


Figure 3. As Fig 1 but for differences between 12-hour forecasts from analyses with and without aircraft data.



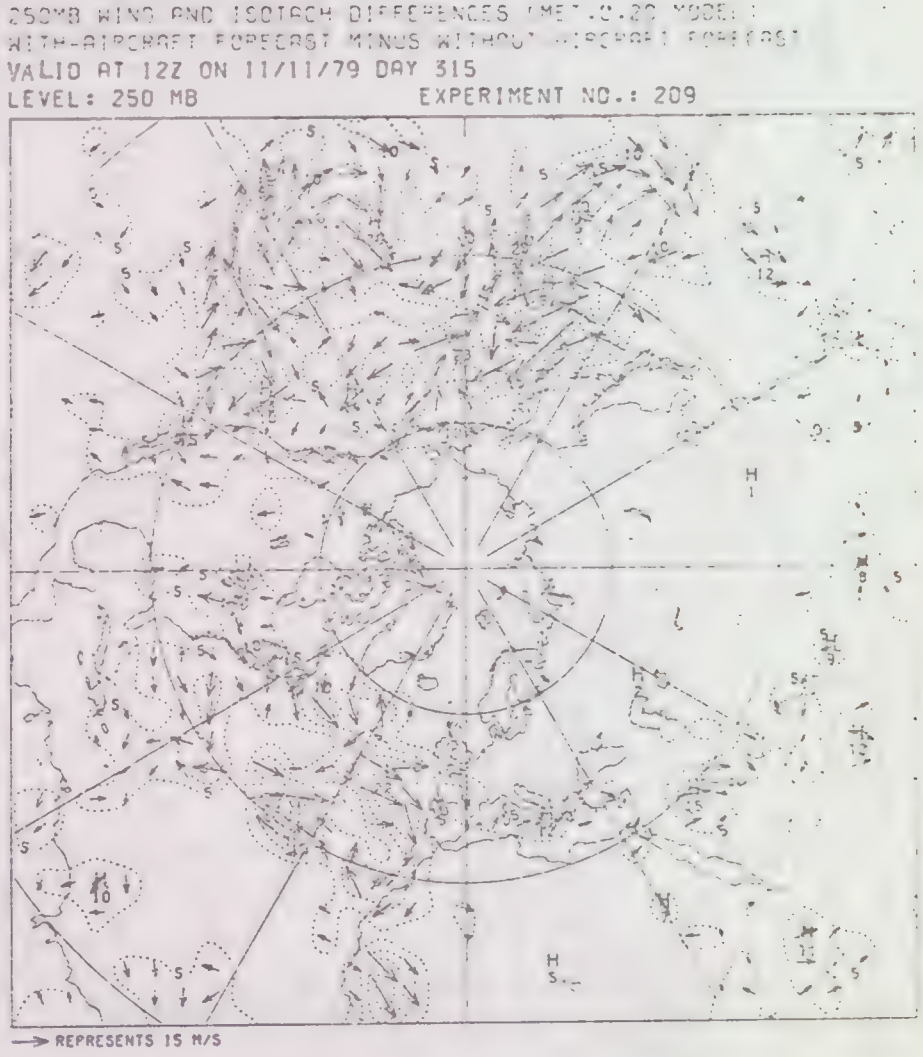
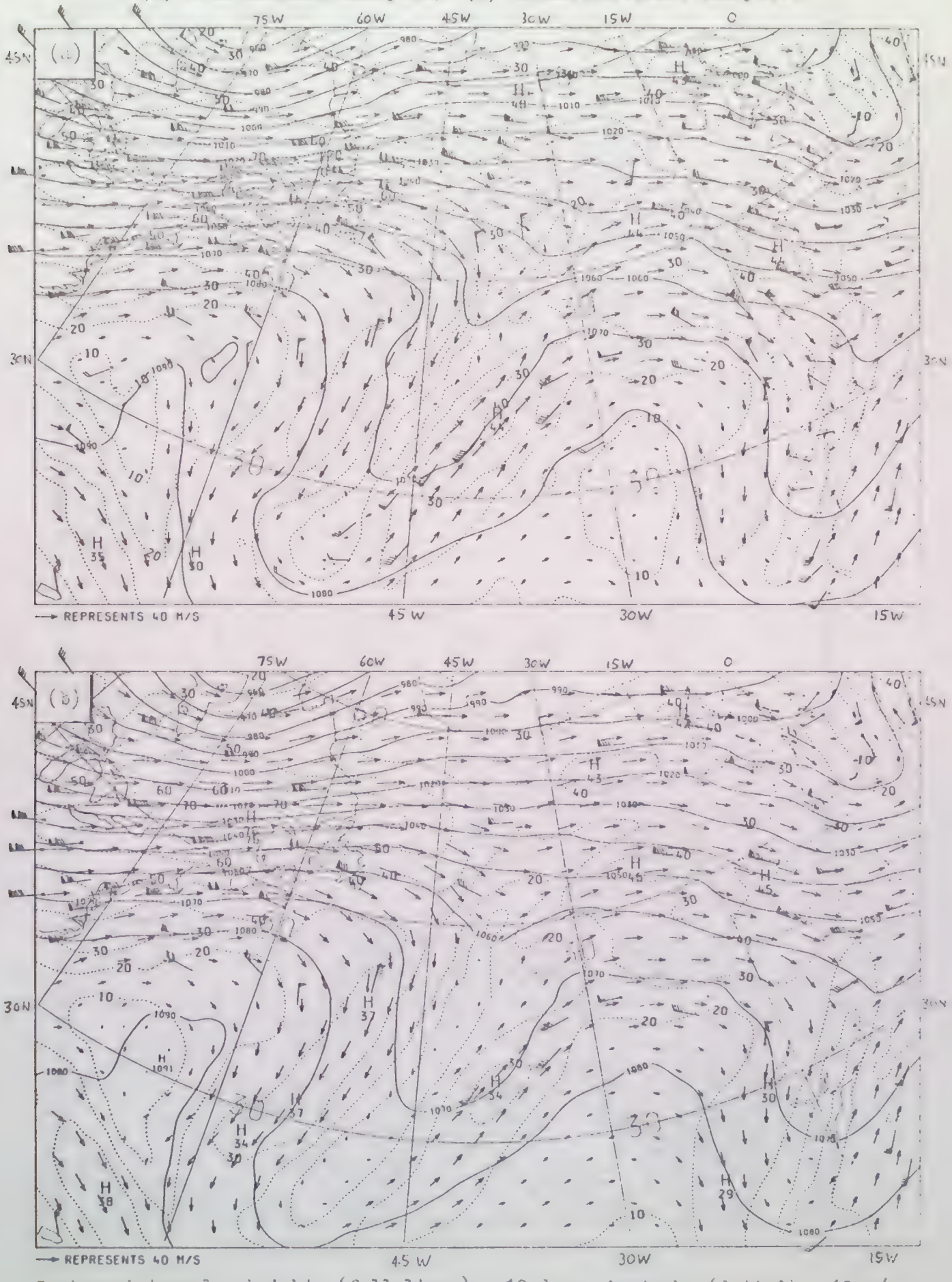
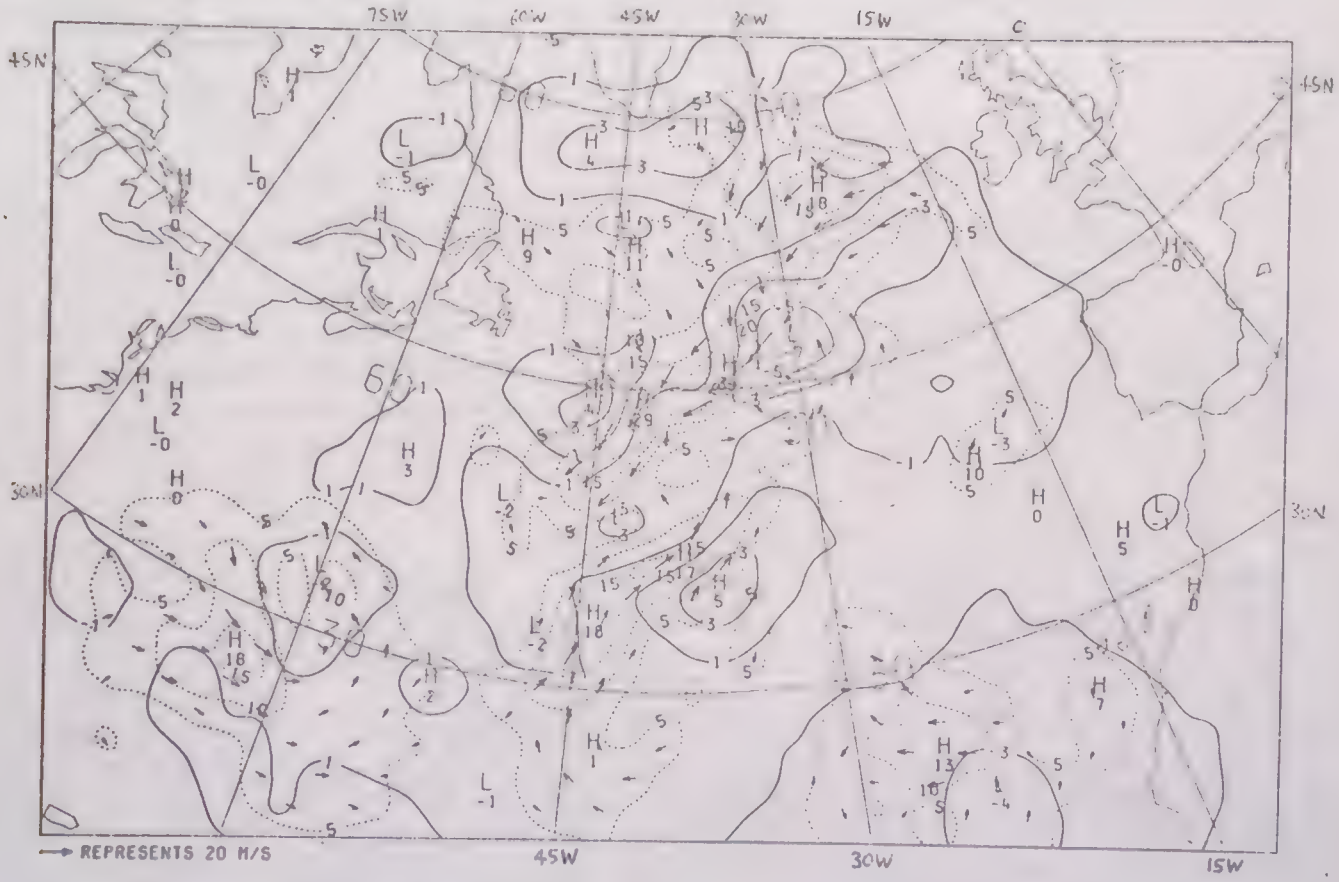


Figure 4. 250 mb height and wind analyses for the North Atlantic, 00Z 11 Nov 1979.
(a) with-aircraft analysis; (b) without-aircraft analysis.



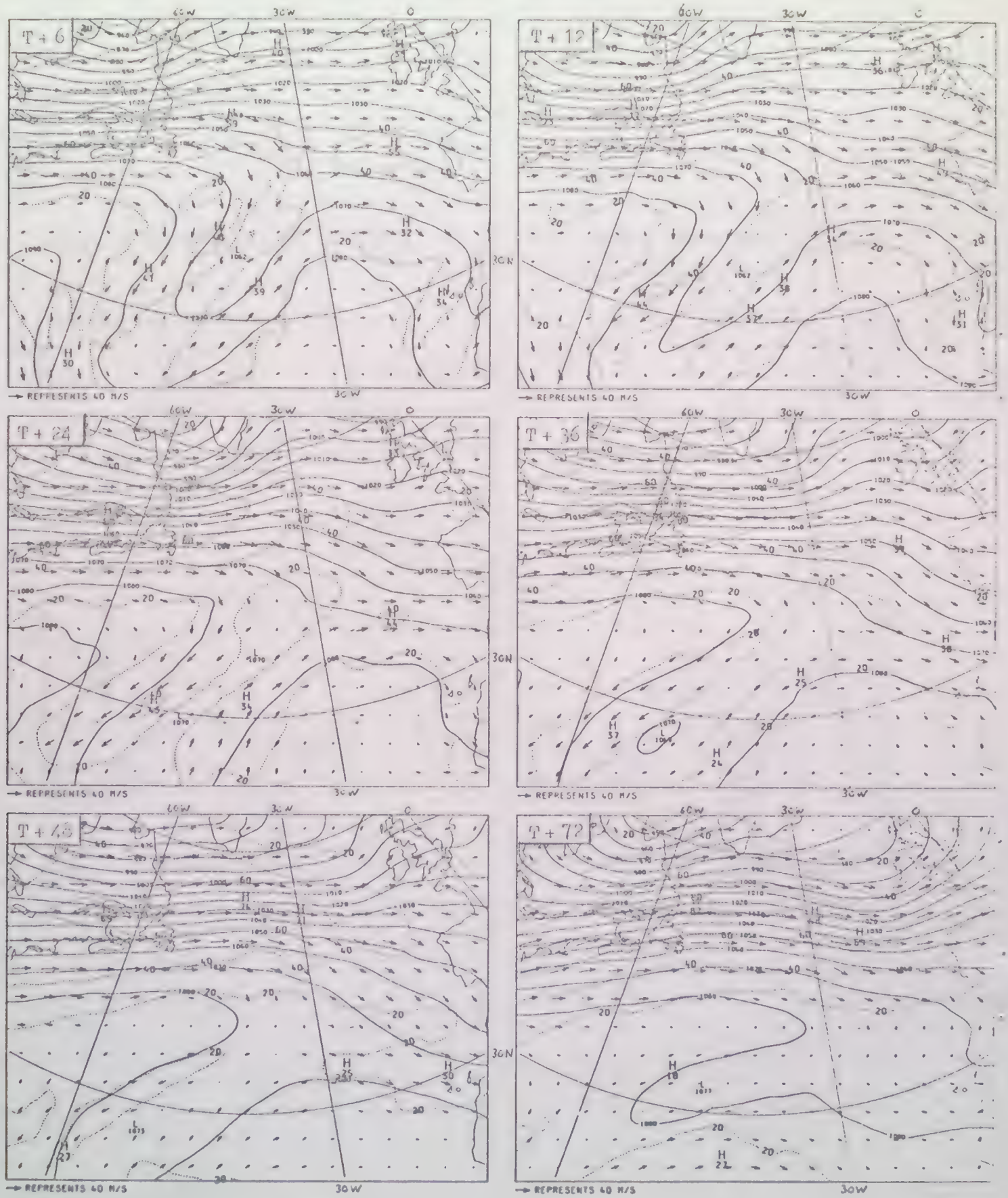
Contour intervals: heights (full lines) - 10 dam, isotachs (dotted) - 10 m/s.
Fleches show wind observations used in analyses (1 full fleche = 10 knots).

Figure 5. Difference between the analyses of Fig 4. (With-aircraft analysis minus without-aircraft analysis).



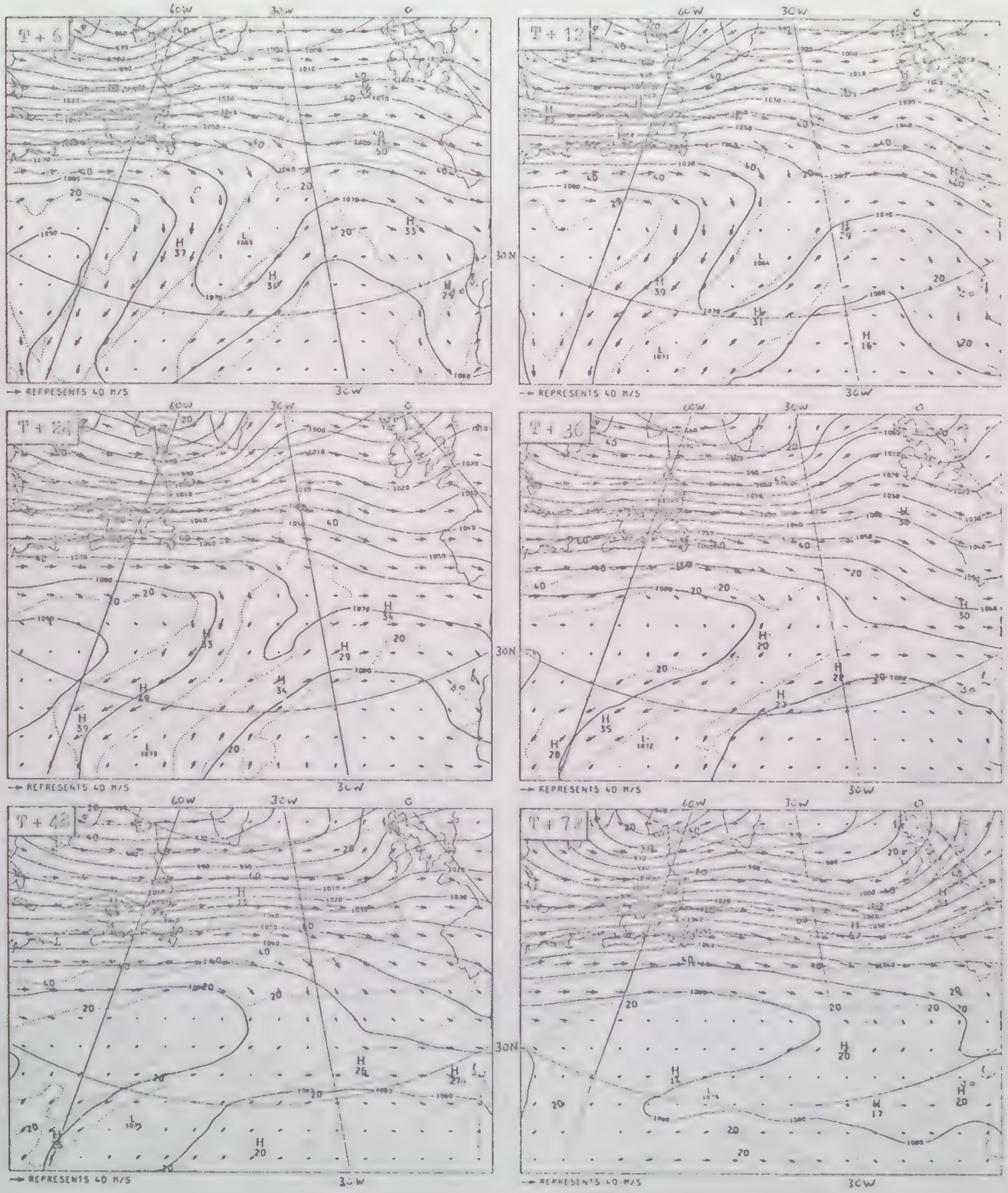
Contour intervals: heights (full lines) - 2 dam, isotachs (dotted) - 5 m/s.

Figure 6. North Atlantic 250 mb charts for forecast from with-aircraft analysis (Fig 4a). Forecast times are shown in the top left corner of each chart.



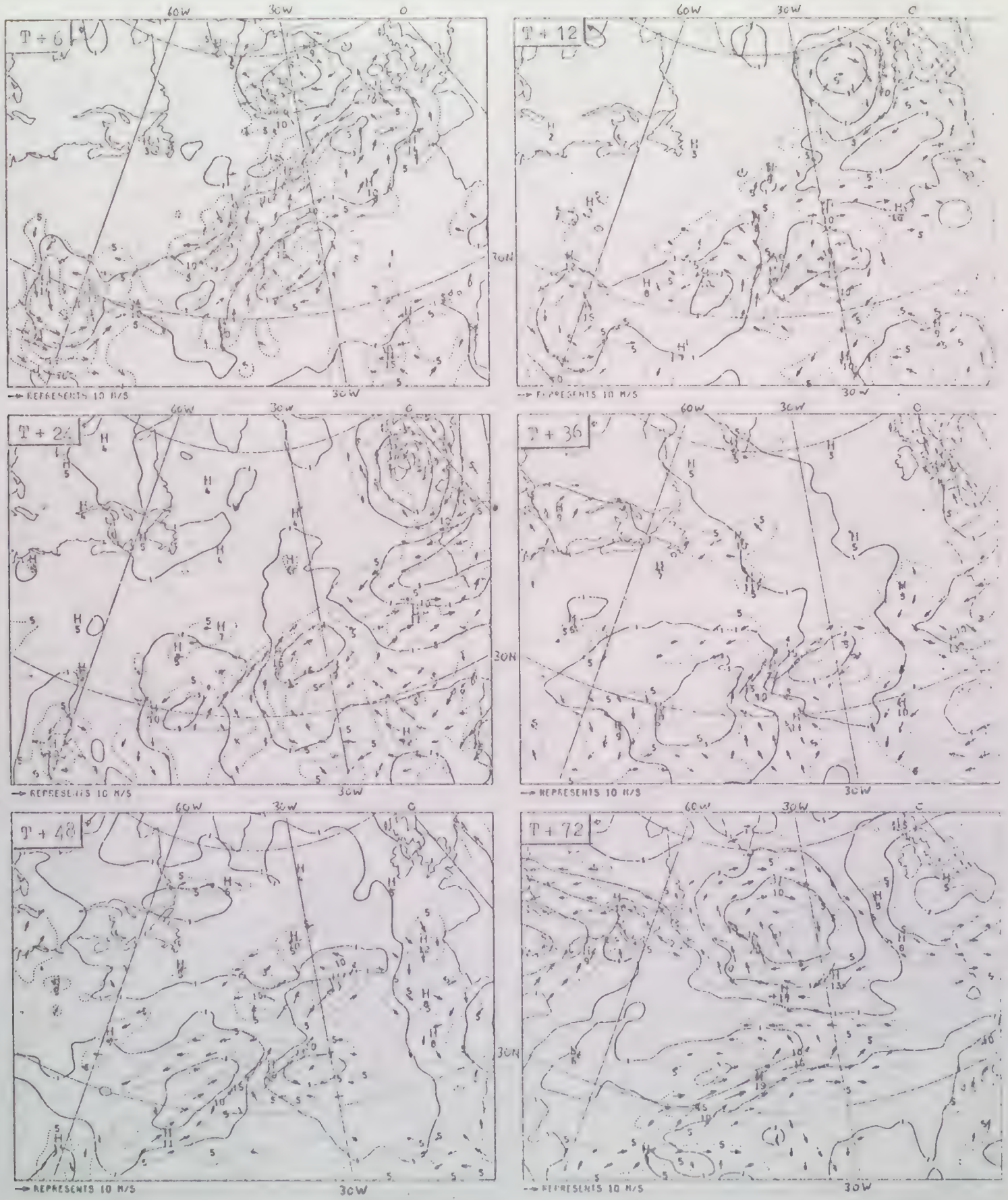
Contour intervals: 10 dam and 20 m/s.

Figure 7. As Fig 6 for forecast from without-aircraft analysis (Fig 4b).



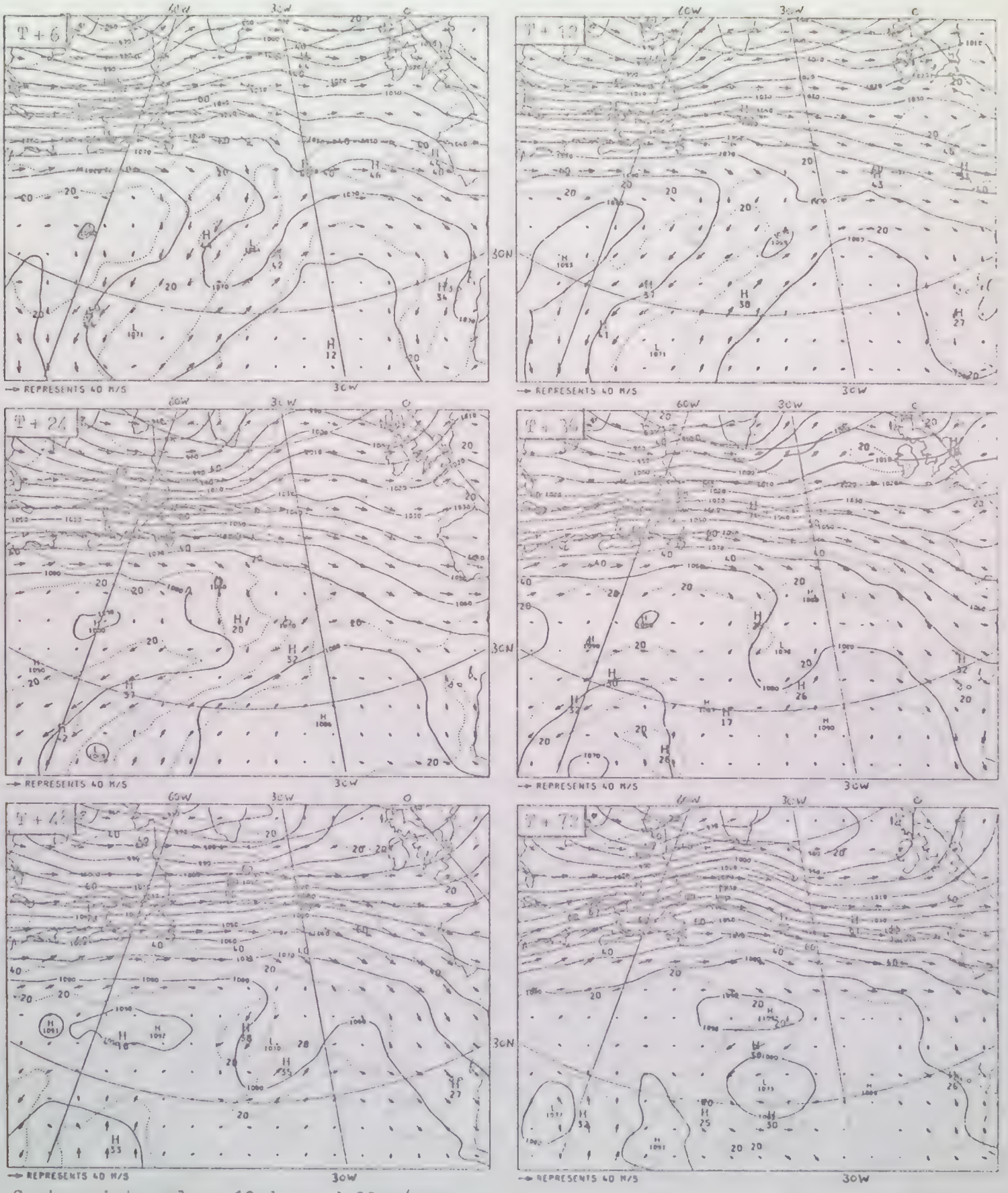
Contour intervals: 10 dam and 20 m/s.

Figure 8. Difference between forecasts from with-aircraft and without-aircraft analyses (Fig 6 minus Fig 7).



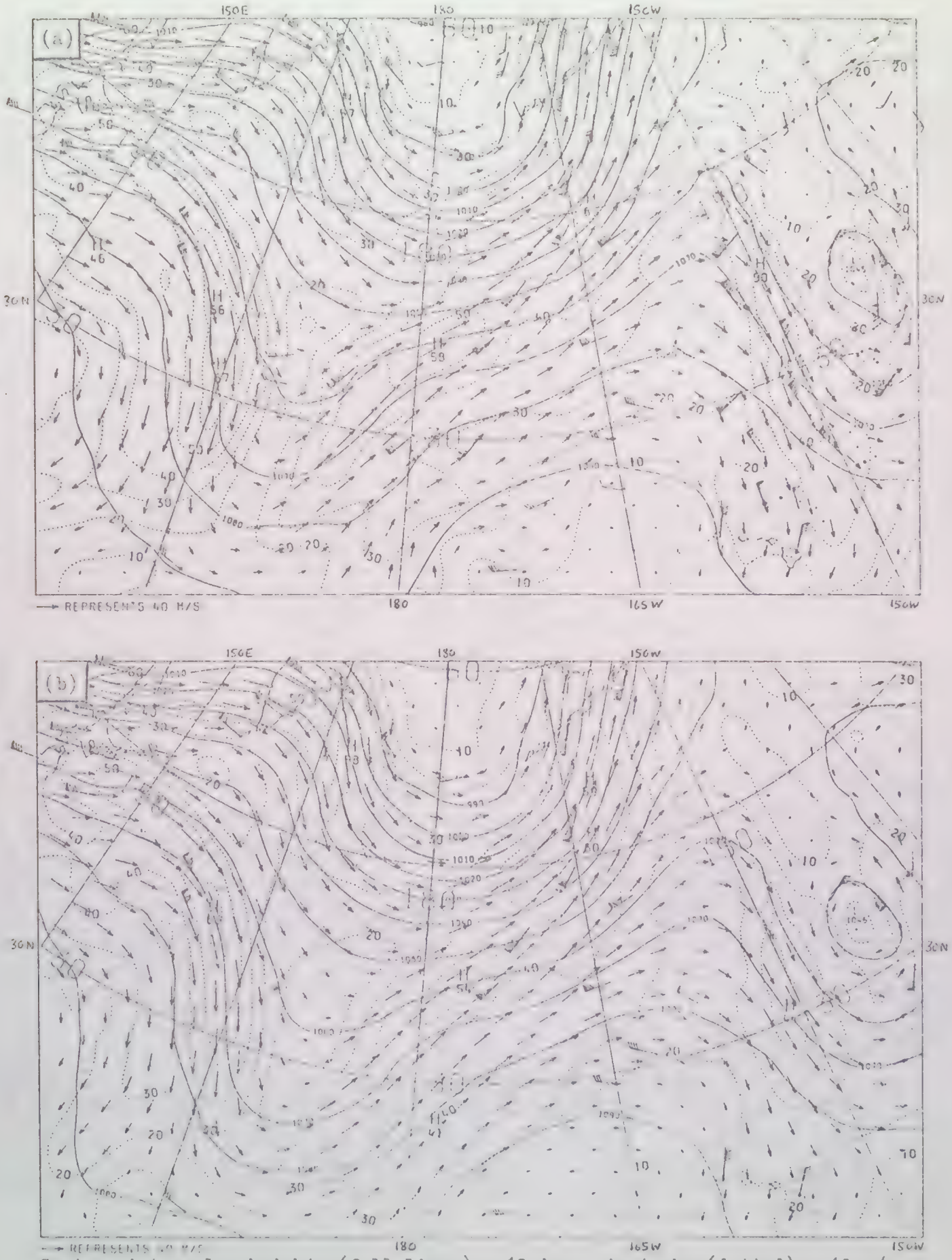
Contour intervals: 2 dam and 5 m/s.

Figure 9. As Fig 6 but analysis charts from the control run.



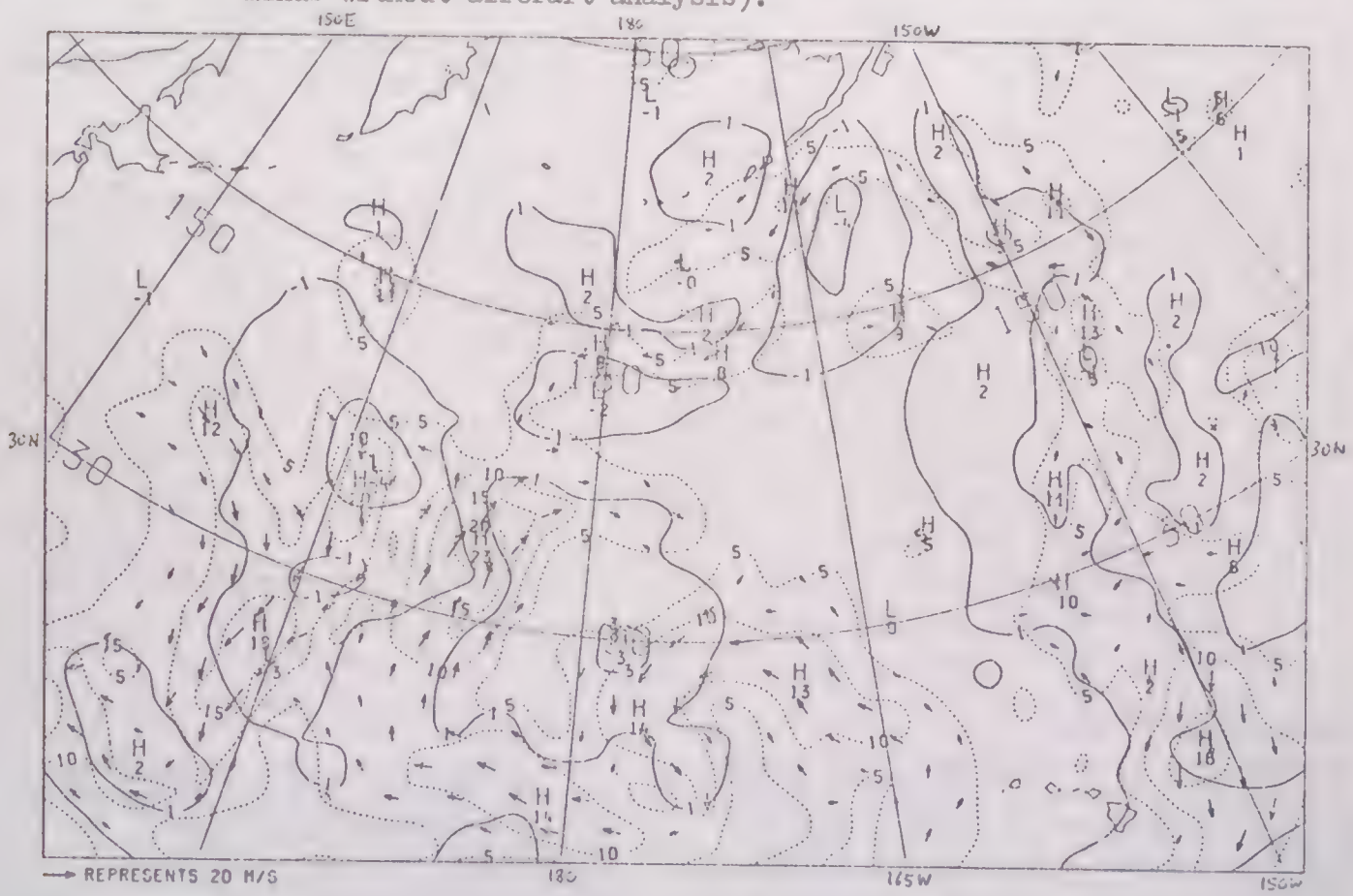
Contour intervals: 10 dam and 20 m/s.

Figure 10. 250 mb height and wind analyses for the North Pacific, 00Z 11 Nov 1979. (a) with-aircraft analysis; (b) without-aircraft analysis.



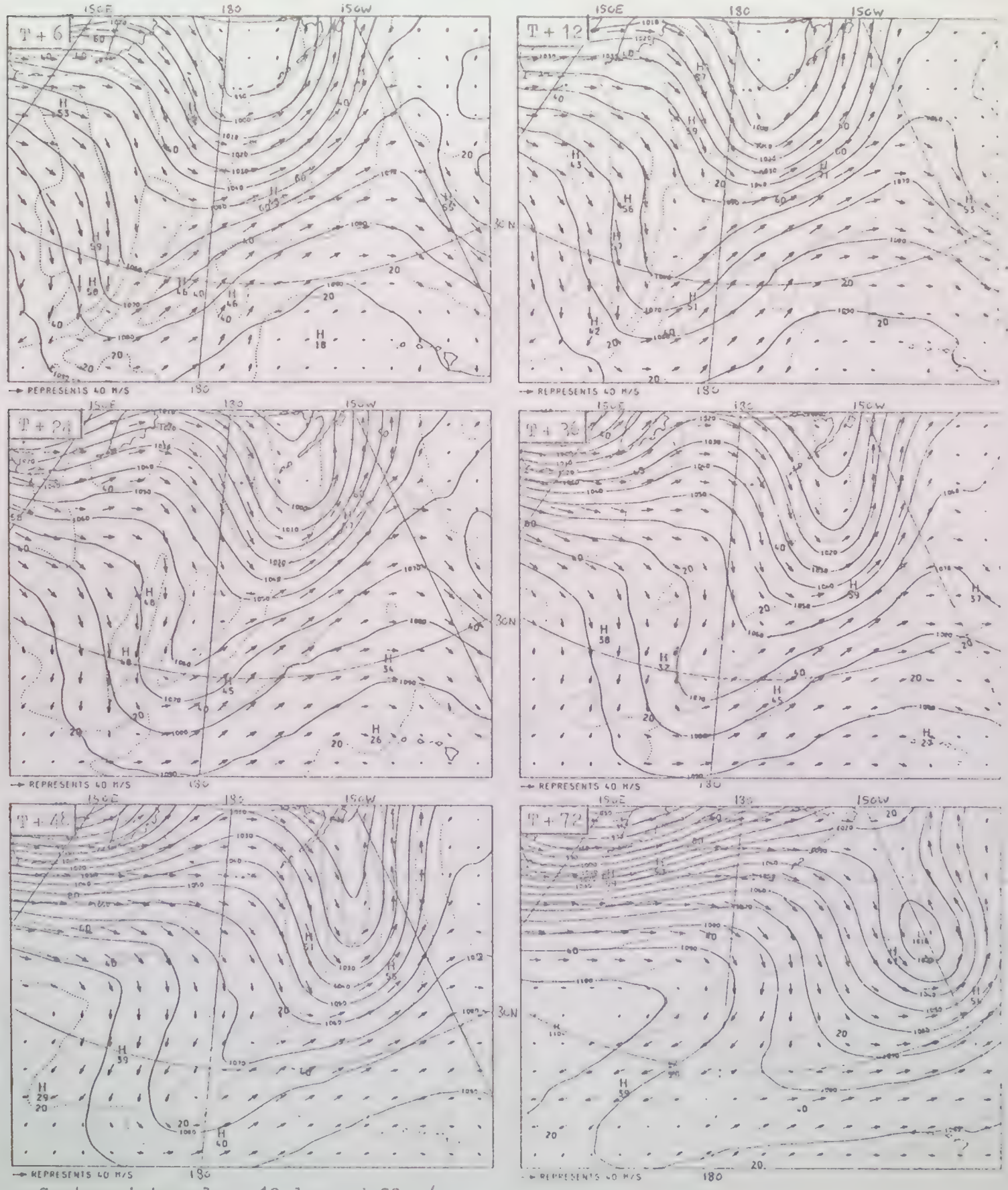
Contour intervals: heights (full lines) - 10 dam, isotachs (dotted) - 10 m/s. Fleches show wind observations used in analyses (1 full fleche = 10 knots).

Figure 11. Difference between the analyses of Fig 10. (With-aircraft analysis minus without-aircraft analysis).



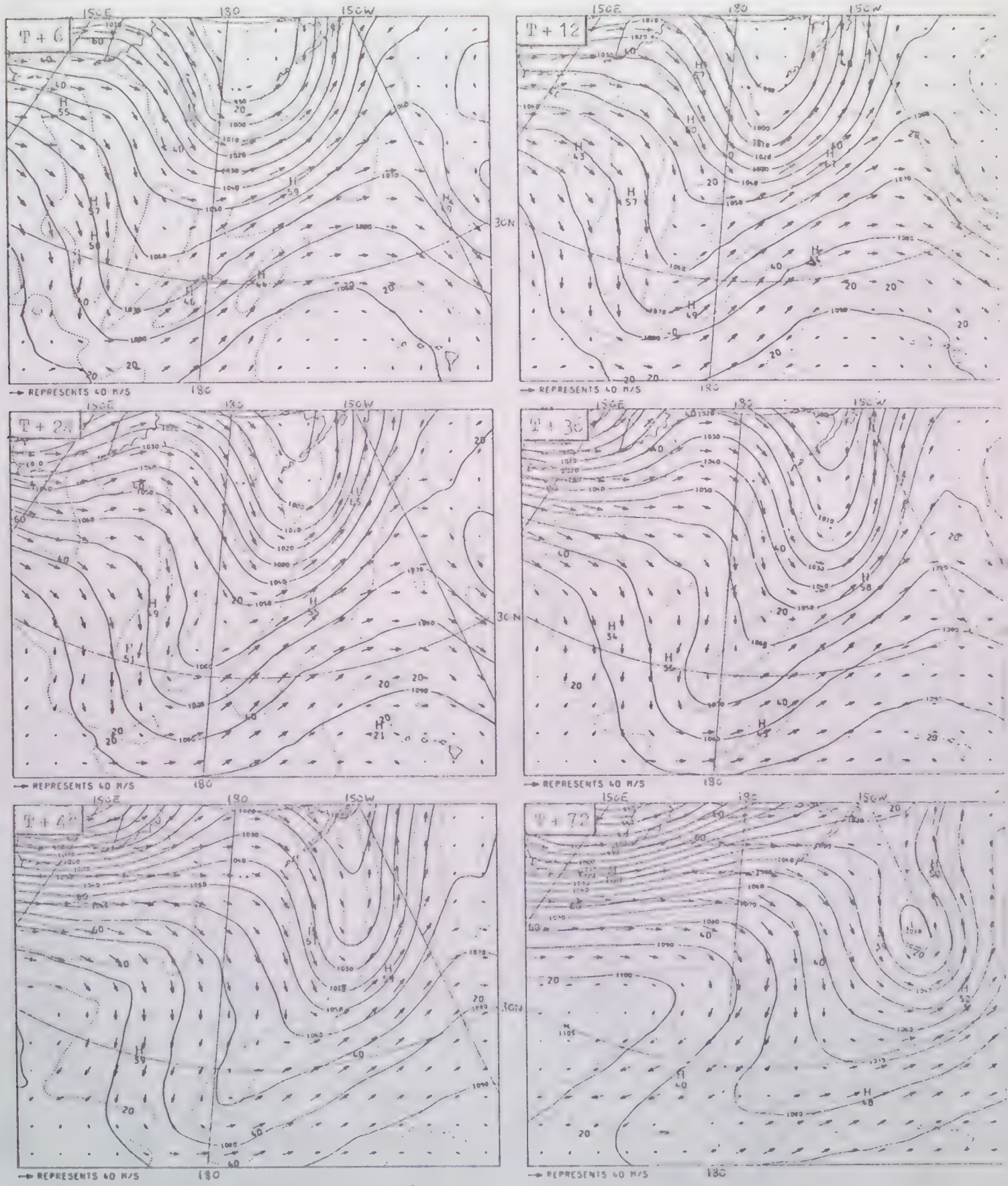
Contour intervals: heights (full lines) - 2 dam, isotachs (dotted) - 5 m/s.

Figure 12. North Pacific 250 mb charts for forecast from with-aircraft analysis (Fig 10a). Forecast times are shown in the top left corner of each chart.



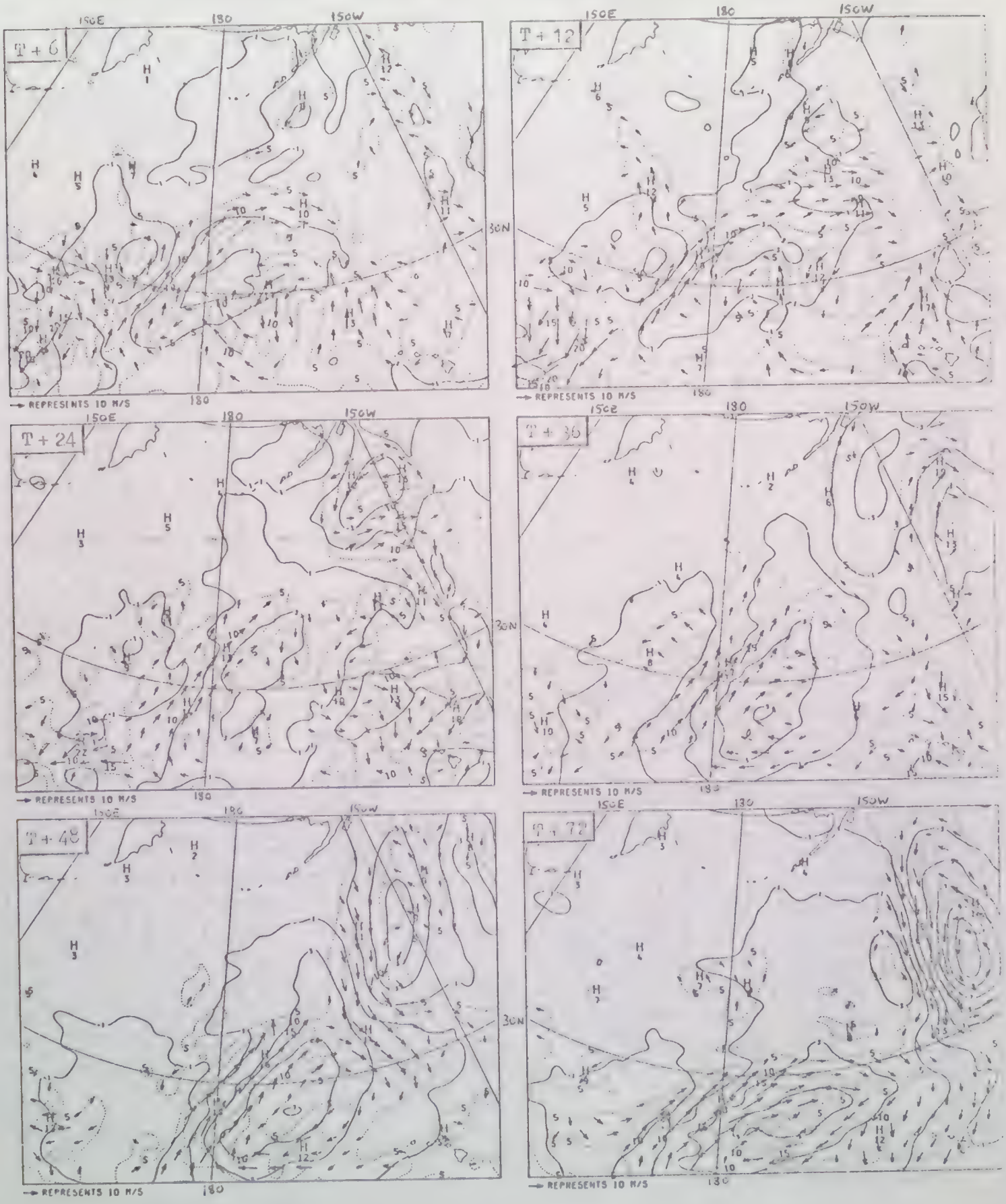
Contour intervals: 10 dam and 20 m/s.

Figure 13. As Fig 12 for forecast from without-aircraft analysis (Fig 10b).



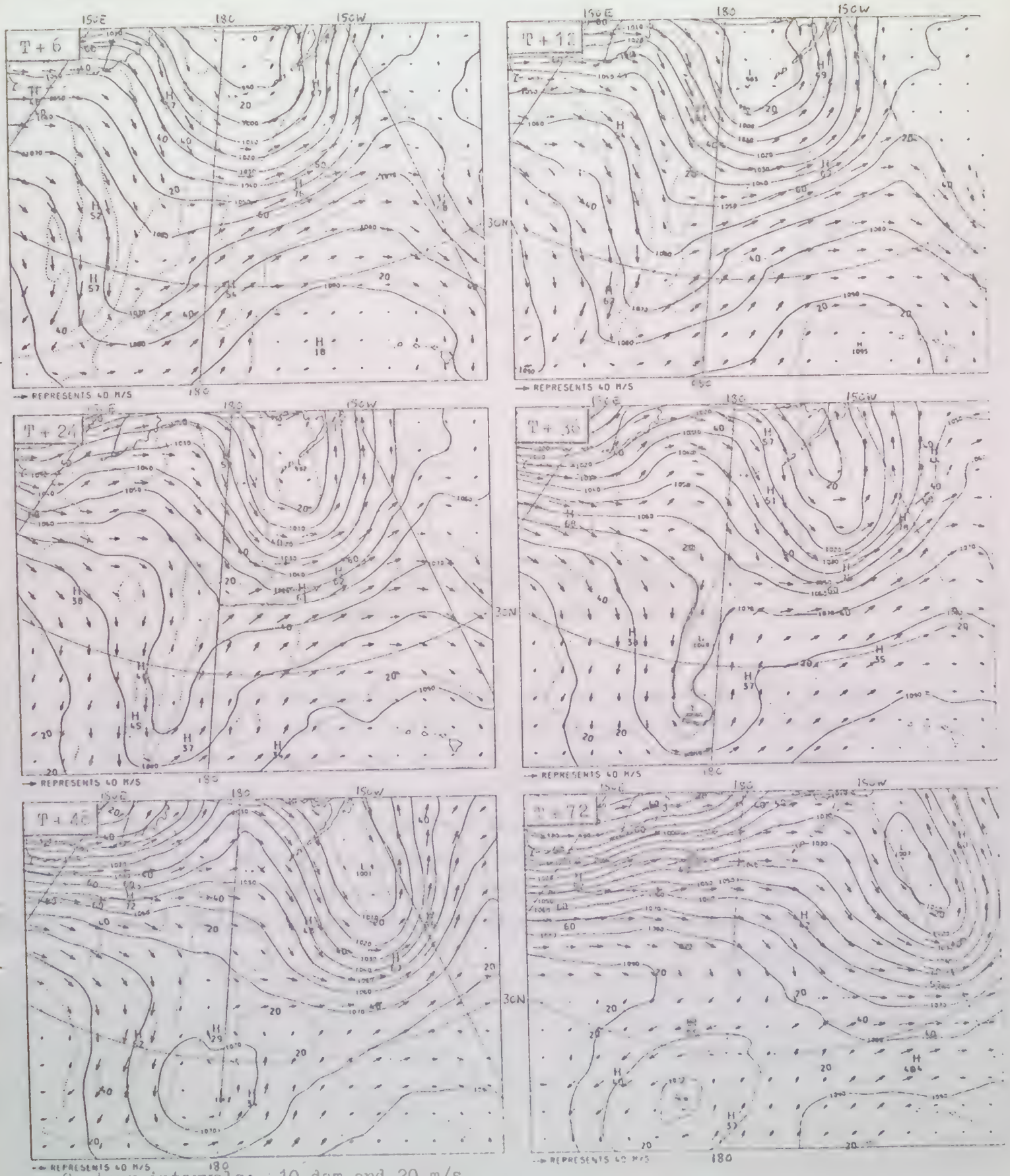
Contour intervals: 10 dam and 20 m/s.

Figure 14. Difference between forecasts from with-aircraft analysis and without-aircraft analysis (Fig 12 minus Fig 13).



Contour intervals: 2 dam and 5 m/s.

Figure 15. As Fig 12 but analysis charts from the control run.



Contour intervals: 10 dam and 20 m/s.

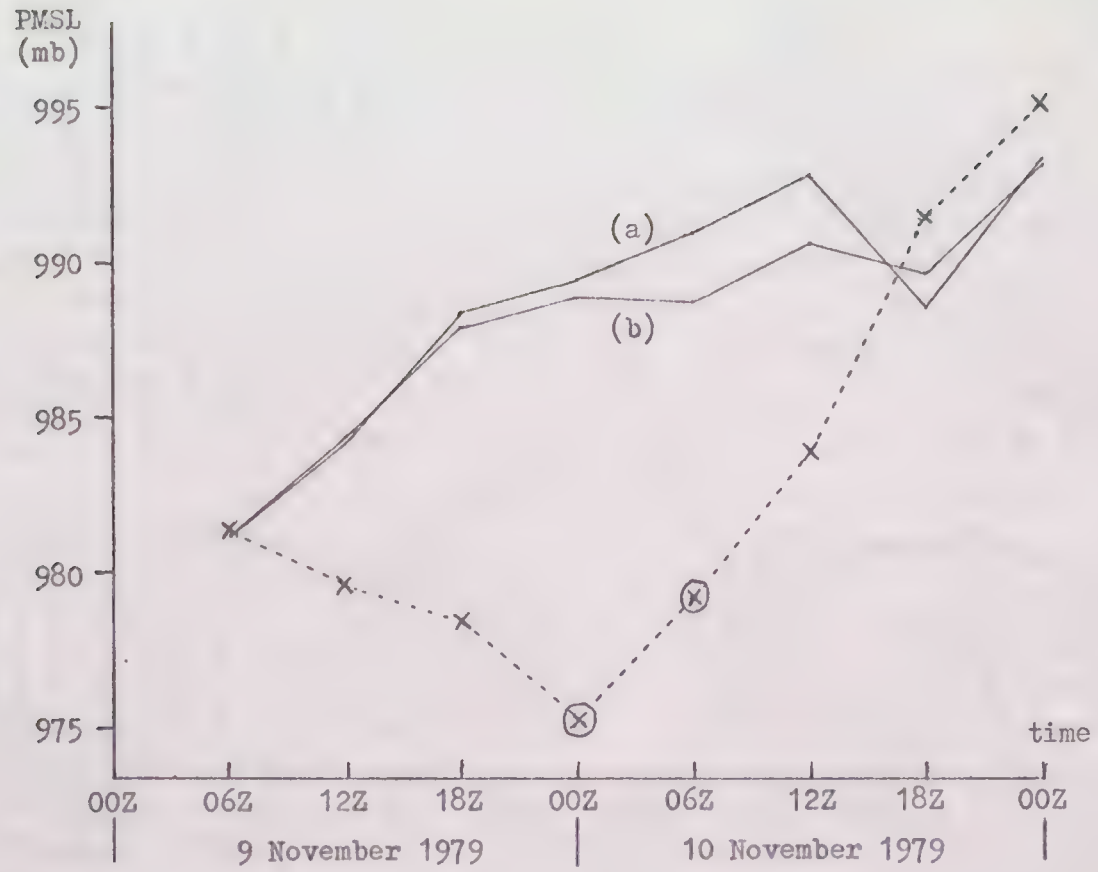
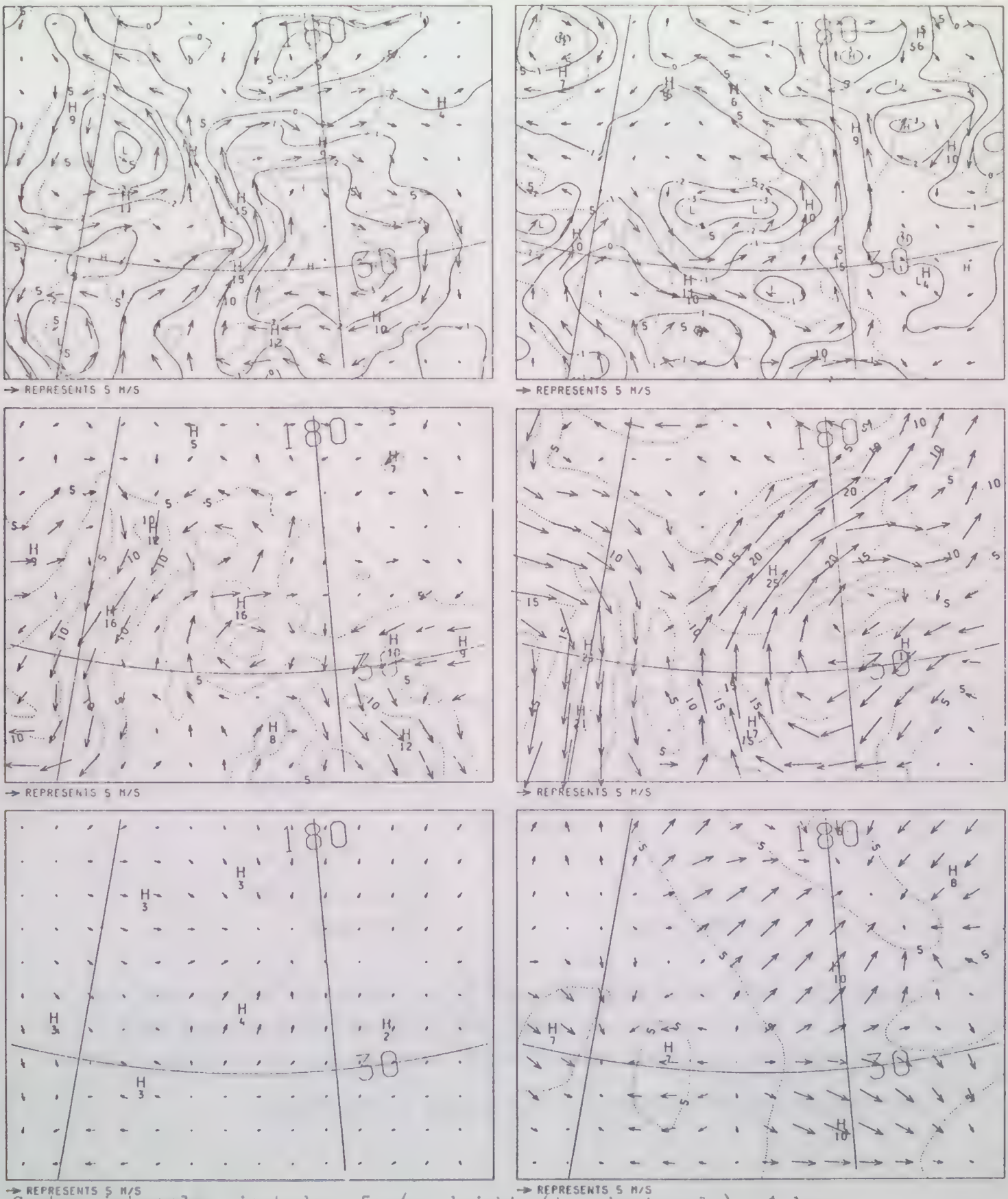


Figure 16. Evolution of sea level pressure in analyses without aircraft data (a) and with aircraft data (b) at the location of a drifting buoy near 54.4 S 3.3 E. Observations from the buoy are marked with crosses and are plotted at the nearest synoptic time (i.e. as would be 'seen' by the model). Circled observations indicate those rejected by the quality control in the no-aircraft analyses but accepted in the with-aircraft analyses. A second buoy nearby gave similar results with rejected observations in the without-aircraft run at 00Z and 06Z on 10 November.

Figure 17. Impact of aircraft data on 250 mb wind analyses for the North Pacific, 00Z 11 Nov 1979. The wind has been resolved into geostrophic component (top), ageostrophic rotational component (middle) and divergent component (bottom). Charts are for the UK15 model (left) and the UK11 model (right).



Contour intervals: isotachs - 5 m/s, heights (top charts only) - 1 dam.

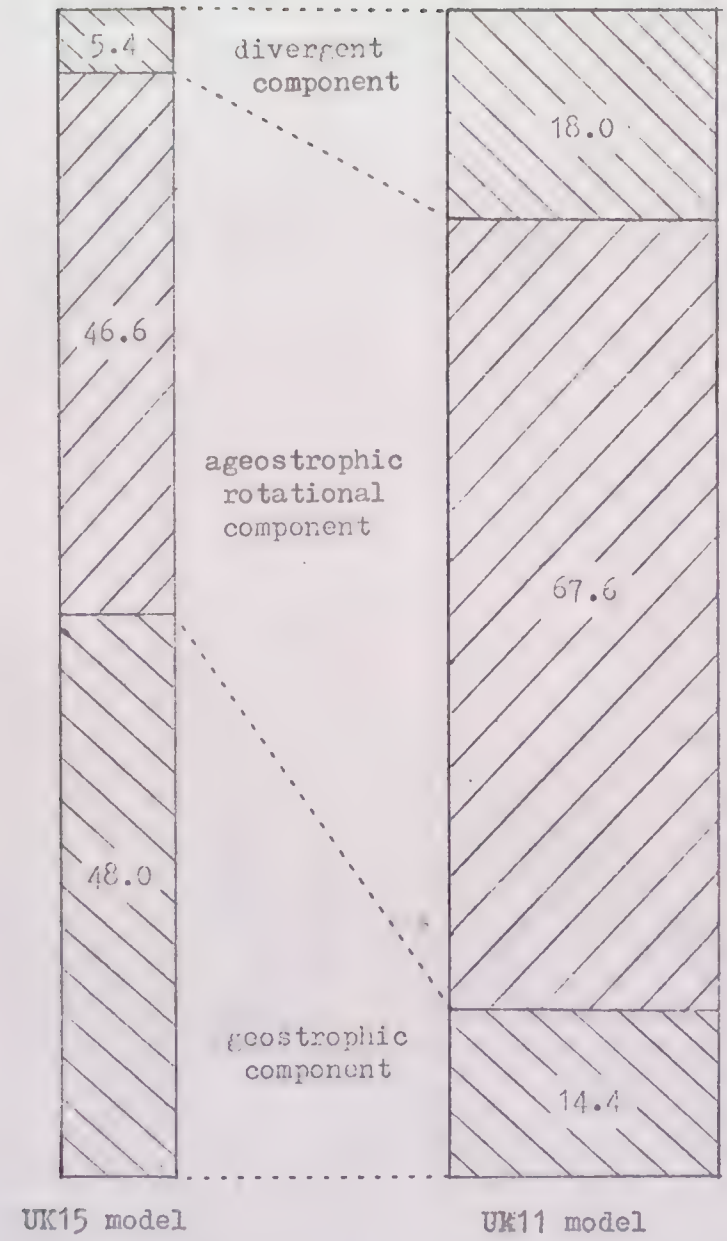
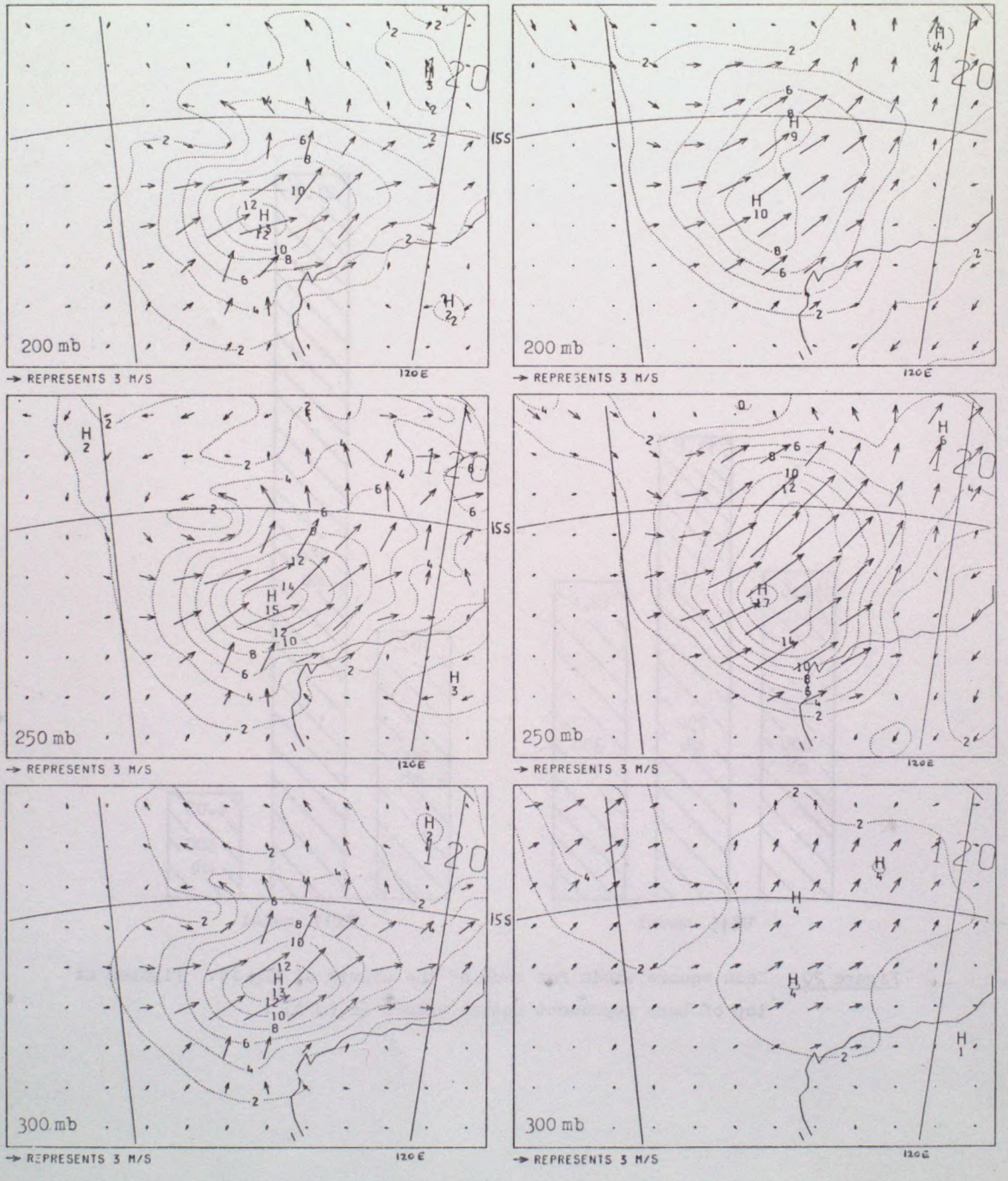


Figure 18. Mean square winds for each of the charts of Fig 17. Bars are scaled to the same height but width is scaled so that equal areas represent equal mean square values. The numbers indicate the value for each component expressed as a percentage of the total.

Figure 19. Impact on wind analyses due to AIREP at 18°S 111.1°E (centre of chart area). Charts are for 200 mb (top), 250 mb (middle) and 300 mb (bottom); UK15 model (left), UK11 model (right). Isotachs are drawn every 2 m/s.



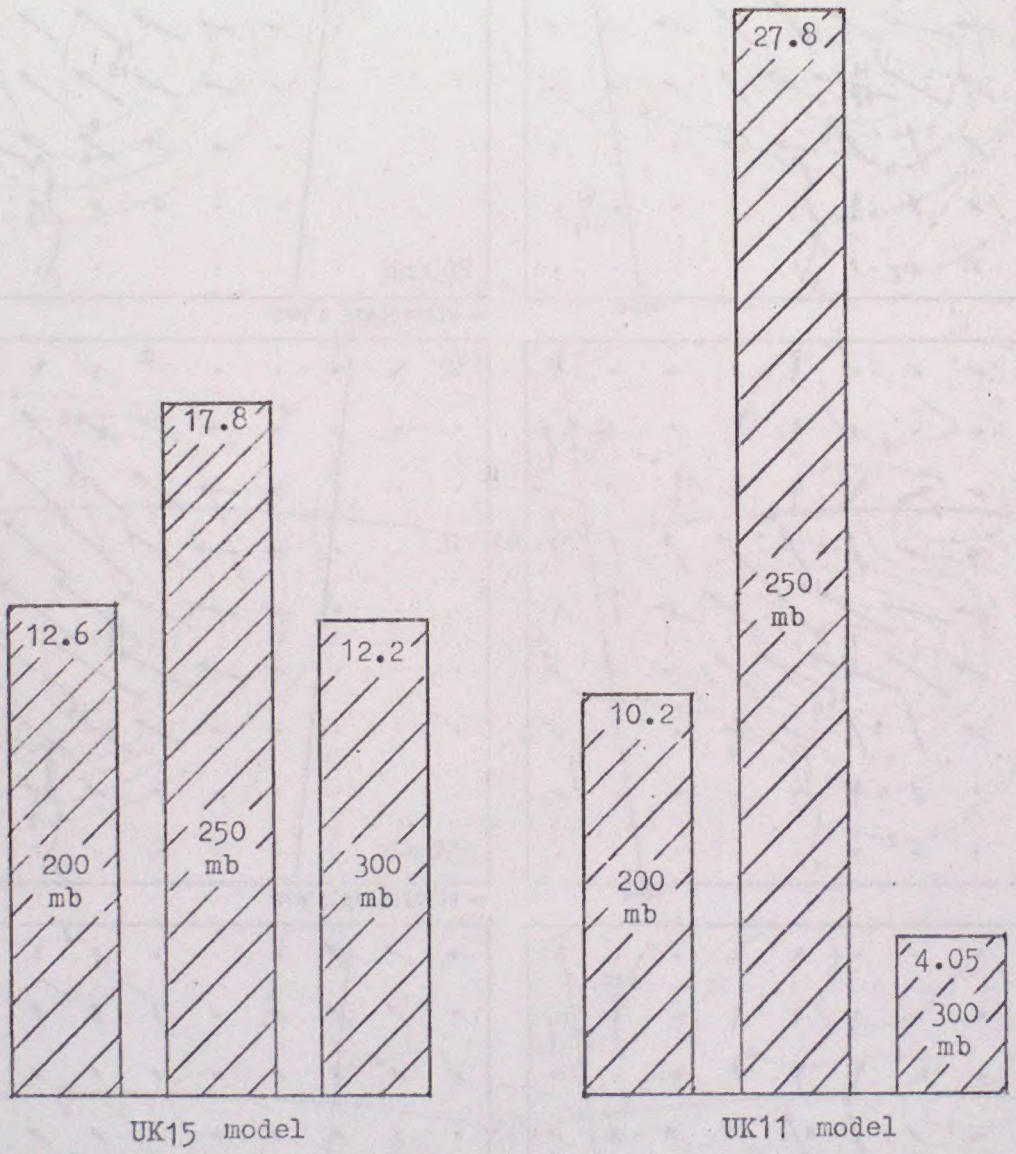


Figure 20. Mean square winds for each of the charts of Fig 19. Figures at top of bars represent actual values in $(m/s)^2$.

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DCTN 1	June 1984	A scheme for incorporating the thermodynamic sea-ice model into a coupled ocean-atmosphere model. C Gordon and M Bottomley
DCTN 2	Sept 1984	The parametrization of the upper ocean mixed layer in coupled ocean/atmosphere models. C Gordon and M Bottomley
DCTN 3	Sept 1984	The response of a simple thermodynamic sea-ice model to GCM forcing appropriate for perennial sea-ice. M Bottomley
DCTN 4	Sept 1984	Potential vorticity in the stratosphere derived using data from satellites. S A Clough, N S Grahame and A O'Neill
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DCTN 16	Jan 1985	Observing system experiments using the Meteorological Office's 15-level model. R A Bromley
DCTN 17	Feb 1985	Atmospheric general circulation simulation of the climate of the Mediterranean region. H Cattle
DCTN 18	Feb 1985	Diurnal variation and cloud in a general circulation model. C A Wilson and J F B Mitchell
DCTN 19	Feb 1985	The sensitivity of the Saharan region in a general circulation model. W M Cunnington and P R Rowntree
DCTN 20	Mar 1985	The impact of aircraft observations on analyses and forecasts from the operational 15-level model. B R Barwell